CALTRANS
ENCROACHMENT PERMITS

GUIDELINES AND SPECIFICATIONS

FOR

HORIZONTAL DIRECTIONAL DRILLING INSTALLATIONS

EFFECTIVE JANUARY 1, 2000, LOCATING AND TRACKING OF THE REAMER DURING THE BACK-REAMING PROCESS IS REQUIRED.

HDD Specifications Developed By:
CALTRANS
Headquarters Office of Encroachment Permits

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FOREWARD

HORIZONTAL DIRECTIONAL DRILLING: TECHNOLOGY, INSTALLATION TECHNIQUES, AND APPLICATIONS

Consultants, contractors, owners, and research institutes from across North America developed these guidelines and specifications for the installation of pipelines and conduits in an urban environment using horizontal directional drilling technology. Several design *rules of thumb* have also been incorporated in order to provide the necessary tools to differentiate between a borehole design, which enhances the probability of a successful installation, or a design which may result in installation difficulties.

Perhaps the fastest growing technology, which has taken the Trenchless Construction Industry over by storm in the past decade. Horizontal directional drilling (HDD) in North America has grown from 12 operational units in 1984 to more than 2000 units operating in 1995.

Equipment and installation techniques used by HDD contractors evolved by merging technologies from the utility, oil field, and water well industries. Currently, a wide range of directional boring units exist in the market place, from mini drilling rigs, which are used for the installation of 50mm (2 in.) utility conduits to maxi rigs, which are capable of installing 1200mm (48 in.) sewer lines. Installation range is determined by many parameters, including rig size, soil conditions and product diameter. Installations as long as 1830m (6000 ft) are known to have been successfully completed. Current commercial HDD equipment can operate in a wide range of soil conditions, from extremely soft soils to full face rock formations with unconfined compressive strengths of 28 MPa (40,000 psi).

Advantages such as reducing disturbance to traffic, businesses and the elimination of restoration costs make this technology an attractive alternative to open excavation for the installation of utility services. Recently, installations of water and sewer force-mains using HDD have been completed in Canada and the United States. While some of these projects involved the crossing of rivers or major traffic corridors, others involved the installation of pipeline products in difficult soil conditions or beneath existing structures.

The installation of gravity sewers, with an acceptable grade accuracy can be maintained during the installation. The ability to install pipes at tight grade tolerances using HDD was made possible by recent improvements in the equipment's locating and tracking accuracy, information feedback capabilities, and increased operational depth of the "walk-over" locating system.

ADVANTAGES of HDD

Traditionally, installation of underground utilities involved open trenching. The contractor had to excavate around existing utilities to get to the required depth. Often sidewalks, pavement, brick paving, sod or other surfaces must be replaced, including the interruption and inconvenience of traffic and the disruption of nearby commercial activities with open cut trenches that must be backfilled.

Excavation requirements in horizontal directional drilling are minimal or non-existent. In crowded urban areas, horizontal directional drilling is increasingly viewed as the preferred technology by virtue of its decreased surface disruption. It minimizes the negative impact on residents, businesses, and eliminates the need for removal, restoration and long-term costs associated with trench settlement are avoided. In open areas, horizontal drilling provides an efficient method for crossing obstacles such as rivers, highways, rail tracks or an active runway.

Vertical shafts **are not** required as drilling commences from the surface. HDD equipment requires a relatively short set-up time, a mini rig can be set up and start boring within an hour. Labor requirements are minimal, as it only takes a two-man crew to operate a small drilling rig. Finally, the borehole profile does not necessarily have to be straight, as it is possible to change the borehole elevation and alignment to avoid existing utility lines.

Other advantages of horizontal directional drilling include:

1. It allows for operation in sensitive soil conditions or environmentally sensitive areas with minimum disturbance to the surrounding environment.

2. It eliminates the cost and time associated with installing de-watering facilities for operations carried out below the ground water table level.

3. Year-round construction is possible.

4. It improves safety by requiring fewer people on-site, reducing possible exposure to contaminants (on environmental projects) and eliminating the risk of cave-ins.

Current applications of directional drilling are outlined in the following section.

APPLICATIONS

The market for horizontal directional drilling is experiencing a continuous growth worldwide, with services provided to a broad base of industries. Applications for horizontal directional drilling include:

Utilities

The installation of utility conduits in urban areas and across rivers and highways is the “bread and butter” of the horizontal directional drilling industry. Over the last five years, utility companies have used horizontal directional drilling extensively for the installation of new networks of power, natural gas and telecommunications (Figure 1).

Municipal Applications

Recent advancements in equipment and tracking systems make the use of HDD cost efficient for projects that involve larger diameter products and stricter placement tolerances, as in the case of many municipal applications.

Pipelines

The oil, gas and petro-chemical industries are another utilizing the directional drilling industry.

Others

The unique characteristics of HDD technology allow it to be applied in many other applications, including slope stability, site investigation, ground stabilization, de-watering, and pipe-reaming.

THE DIRECTIONAL BORING UNIT

The HDD drill rig provides torque, thrust, and pullback to the drill string. The drill drive assembly resides on a carriage that travels under hydraulic power along the frame of the drill rig.

The thrust mechanism for the carriage can be a cable, chain or screw, or a rack and pinion system. Table I, lists the three general categories of drilling rigs used in the industry.

Small Rigs are mounted on a trailer, truck, or self-propelled track vehicle (Figure 1). These systems are designed for drilling in relatively soft semi-consolidated formations and are used primarily for installation of utility conduits in congested urban areas. They are not suitable for drilling gravel, cobble or other formations where borehole stability is difficult to maintain.

Medium drilling rigs are used to install conduits and pipelines up to 400mm (16”) in diameter. Average installation distance may range from 150 to 600m. They are particularly suitable for the installation of municipal pipelines, as they are sufficiently compact to be used in urban areas, while at the same time they have the capacity to install relatively large diameter products beneath highways, subdivisions, and rivers. Bores can be installed in unconsolidated to consolidated sediments.

Large rigs typically involve a large operation with multiple trailer-mount support equipment and substantial mobilization and demobilization periods.

High operating costs make their use somewhat prohibitive in the utility installation market; and they are employed primarily in the pipeline and resource exploration industries. These large units may be used in the installation of large diameter products (24”-48”) or exceptionally long boreholes (over 1000m).

Table I: Typical Characteristics of HDD Rigs (May 1994)

	SMALL RIGS	MEDIUM RIGS	LARGE RIGS
Thrust/Pullback	< 20,000 lbs.	20,000 - 80,000 lbs.	> 80,000 lbs.
Maximum Torque	< 2000 ft./lbs.	2000 - 20,000 ft./lbs.	> 20,000 ft. lbs.
Drilling Speed	> 130 RPM	130 - 200 RPM	< 200 RPM
Carriage Speed	> 100 ft/min.	90 - 100 ft./min.	< 90 ft./min.
Carriage Drive	Cable or Chain	Chain or Rack & Pinion	Rack & Pinion
Drill Pipe Length	5-10 ft.	10 - 30 ft.	30 - 40 ft.
Drilling Distance	< 700 ft.	700 - 2000 ft.	> 2000 ft.
Power Source	< 150 HP	150 - 250 HP	>250 HP

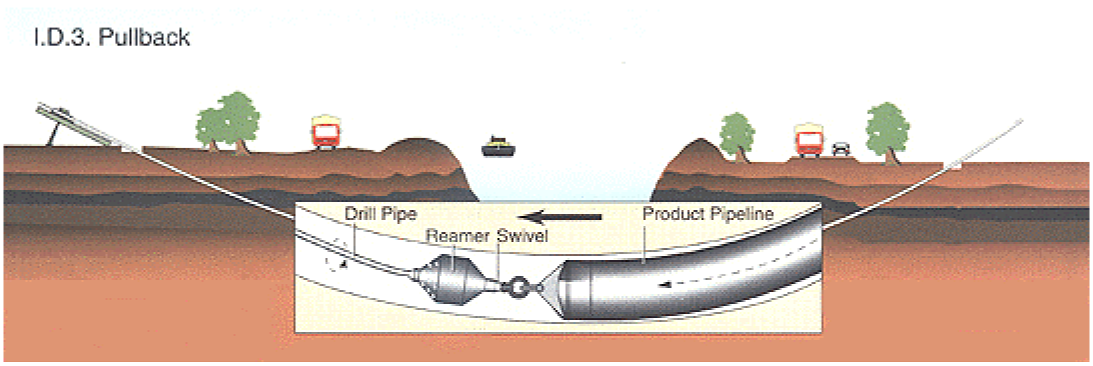
BORE INSTALLATION

The pilot bore is launched from the surface and proceeds downward at an angle until the necessary depth is reached. The path of the bore is gradually brought to a horizontal position and the bore head is steered to the designated exit point, where it is brought back to the surface following a curved path.

During the drilling process, the bore path is traced by interpretation of electronic signals sent by a monitoring device located near the head of the drilling string. At any stage along the drilling path, the operator receives information regarding the position, depth and orientation of the drilling tool, allowing him to navigate the drill head to its target.

After the pilot string breaks the surface at the exit location, the bit is removed from the drill string and replaced with a back-reamer. The pilot borehole is then back-reamed, enlarging the hole to the desired diameter while simultaneously pulling back the line product behind the reamer.

Figure 2: Typical Pull Back Operation (DCCA, 1996)



The above description is typically referred to as a "continuous" borehole (Fig. 2). In some instances it is desired to drill a single-ended borehole, commonly named a "blind borehole". Here construction, reaming and all other activities take place at the location of the entry pit.
This type of installation is more complicated and expensive than the "continuous" borehole described above, and is used only in environmental applications for either collecting soil samples or installing horizontal wells beneath structures. During the boring process drilling fluid is injected under pressure ahead of the advancing bit. The drilling fluid creates a 'mud cake' along the perimeter of the borehole, thus stabilizing the borehole and reducing the friction during the pullback operation.

In the following sections commonly used drilling/steering tools, navigation systems and drilling fluids are discussed in detail. Also, design considerations for a typical horizontal-crossing project are outlined.

DRILLING & STEERING

Drilling curved and horizontal boreholes requires specialized drilling equipment. This equipment is contained in a bottom hole assembly (BHA) that consists of a drilling tool, a bent sub-assembly, and a steering/tracking tool. This section is devoted to drilling and steering tools.

Perhaps the two most common types of down-hole drilling/steering tools used in the HDD industry are compaction tools and down-hole mud motors. Compaction heads consist of a wedge shaped drilling bit, which is used for cutting/displacing the soil as well as for steering.

To bore a straight hole the drill string is rotated and pushed simultaneously. When a correction in direction is required, rotation stops and the drilling head is preferentially oriented in the borehole. Then the entire drill string is pushed forward by the drill rig. As the slant on the face of the wedge is pushed against the soil, the entire assembly is deflected in the desired direction. After the steering correction is completed, rotation is resumed until another correction is needed.

Compaction type drilling tools are most commonly used in mini and midi size drilling rigs to drill through soft to medium consolidated soils as well as loose and dense sands. In the presence of gravel or hard clay, these drilling tools tend to wear out rapidly. They are not suitable for drilling in rock formations.

When using compaction heads, difficulties in steering may be encountered while attempting to drill in very soft soils as the resistance to the deflector plate may not be large enough to counteract the tendency of the drill string to dive vertically under its own weight. The solution to this problem is to use a larger deflector plate. Steering can also be improved by increasing the flexibility at the head of the drill string by adding a length (approximately 6-9m) of smaller diameter more flexible drill rod behind the drill bit. The smaller diameter rod is coupled with the larger diameter drill rod that provides the tensile strength required for pull back.

Mud motors are used in ground conditions ranging from hard soil to rock (up to 40,000 psi unconfined compressive strength). This system uses a positive displacement motor, from the flow output of the mud pump, it generates torque and rotation at the drill bit. The direction control is brought about by a small bend in the drill string just behind the cutting head. For example, if a right turn is desired the bend is orientated to the right, enabling the drill path to advance in a smooth radius bend to the right. As with the compaction heads, once the correction is made the complete drill string is rotated to continue boring straight in the new direction. This method is rather costly in comparison to a compaction head, and is less common in the utility installation industry.

The advantage is that the mud motor does the cutting of the formation. This reduces the drill string rotation requirements, thus making it possible to drill long boreholes (up to 2000m) to substantial depths. On the negative side, mud motors are substantially more expensive than compaction heads and require hundreds of liters of drilling fluids per minute.

TRACKING

Tracking refers to the ability to locate the position, depth and orientation of the drilling head during the drilling process. Accurate tracking capability is essential for the completion of a successful bore. Tracking tools are generally one of three types: 1) electronic beacon systems (“walkover”); 2) magnetometer-accelerometer systems; or 3) inertial navigation systems.

A “walkover system” consists of three components, namely a transmitter, a receiver and a remote monitor. Transmitters (or sondes) are available to maximum depths of 10, 15 or 30 meters. A battery powered transmitter (aside from the 30m sonde which requires hard wiring) is located in the bore hole assembly (BHA) near the front of the drill string. It emits a continuous magnetic signal.

The receiver is a portable, hand held unit, which measures the strength of the signal sent by the transmitter. This information allows users to accurately determine the location of the drill head in terms of position, depth and orientation. Additionally, information regarding battery life and transmitter temperature is provided.

The remote monitor is a display unit installed at the drilling rig in front of the operator. It receives and displays the information provided by the receiver. The operator uses this information to navigate the drilling head below the surface. The data received by the remote is recorded to provide an ‘as-built’ profile of the bore path for future reference. The accuracy of this tool as stated by the manufacture is ±5% of the tool’s true depth.

When access to a location directly above the borehole alignment is not possible, or when borehole depth exceed 30 meters, a more sophisticated navigation systems should be used. Two systems commonly employed are the magnetometer-accelerometer system and the inertial navigation system. The magnetometer-accelerometer system uses three magnetometers to measure the position (azimuth) of the tool in the earth’s magnetic field and three accelerometers to measure the position (inclination) of the tool in the earth’s gravitational field.

The steering tool transmits information via a wire line to a computer at the surface where the azimuth, inclination and orientation of the tool face are calculated. The accuracy of this system, as stated by the Manufacture, is ±2° in azimuth and ±2% in true depth. As far as operating depth and distance from the drilling rig, this steering tool does not impose any limitation on the rig’s operating range.

Disadvantages of this system include susceptibility to magnetic inferences from buried metal objects and power lines. Thus, some magnetic-accelerometer systems use a secondary survey system (named "Tru-Track") to account for local magnetic influences on the down-hole probe.

The secondary survey system induces a known magnetic field at the ground surface through a copper wire surface grid. A computer program connected to both the surface magnetic field and the steering tool compares the magnetic field measured by the steering tool and the theoretical magnetic field induced by the system, and compensates for local magnetic interference. Such secondary survey systems can be effectively used to a depth of 30m.

The inertial navigation system uses a system of three gyroscopes and three accelerometers to measure the azimuth and the inclination of the steering tool, respectively. The gyroscopes are aligned to True North at the ground surface before the survey is made. Any deviation from True North during the survey is detected by the gyroscopes and relayed to the surface where the azimuth, inclination, and drilling tool orientation are calculated by a computer.

Both systems are expensive ($80,000) and **require expert operators**, thus most drilling contractors hire the services of companies such as Sharewell Inc. and Inrock Guidance Systems Inc., which specialize in operating these systems.

DRILLING FLUIDS

Drilling fluid is composed of a carrier fluid and solids (clay or polymer). The carrier fluid carries the solids down the well bore where they block off the pore spaces on the borehole wall. The blockage is referred to as a filter or mud cake. The ideal mud cake will form quickly during construction of the well bore and prevent intrusion of drilling fluid into the formation. At times additives such as detergents are added to the drilling fluids to counteract some of the formation characteristics such as swelling and stickiness.

The principal functions of drilling fluids used in HDD are:

1. To transport excavated drill cuttings to the surface by suspending and carrying them in the fluid stream flowing in the annulus between the well bore and the drill rod.

2. To clean build-up on drill bits or reamer cutters by directing high-velocity fluid streams at the cutters. This also cools the bits/cutters and electronic equipment.

3. To reduce the friction between the drill string/well product and the well bore wall aided by the lubricating properties of the drilling fluid.

4. Stabilizing the well bore, especially in unconsolidated soils by building a low permeability filter or mud cake lining, and exerting a positive hydrostatic pressure against the well bore wall. Thus preventing collapse as well as formation fluids from flowing into the well bore or drilling fluids from exiting the well bore into the formation (lost of circulation).

5. To provide hydraulic power to downhole mud motors if used.

DESIGN CONSIDERATIONS

Typical products installed using an HDD rig include Steel, High Density Polyethylene (HDPE) or Polyvinyl Chloride (PVC) conduits, as well as direct buried cables. During installation the pipeline product experiences a combination of tensile, bending and compressive stresses. The magnitude of these stresses is a function of the approach angle, bending radius, product diameter, length of the borehole and the soil properties at the site.

By properly selecting the radius of curvature and type of product, the design engineer can ensure that these stresses do not exceed the product capacity during the installation. Ideally, the design should call for a minimum number of joints. If joints are necessary, flush joints (butt fusion/welding) are preferable to glued or treaded joints, which tend to increase the drag on the product in the borehole.

Other considerations include minimum cover, minimum separation from existing utilities, tolerances for deviation in the vertical and horizontal profiles, and maximum true depth (if depth exceeds the range of a walkover tracking system the project cost may increase significantly).

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FOR

INSTALLATION BY HORIZONTAL DIRECTIONAL DRILLING TECHNOLOGY

Horizontal Directional Drilling, another acceptable method of placing carrier pipe or casing pipe, involves the initial drilling of a pilot bore approximately 50mm (2 inches) to 125mm (5 inches) in diameter along a predetermined bore profile utilizing a combination of both mechanical and jetting techniques. Drilling is accomplished by means of surface launched drilling equipment (typical) or pit launched drilling equipment.

Once the pilot hole is completed the product pipe is attached to the drill rod with a reamer and swivel. The reamer enlarges the pilot hole typically 1.2 to 1.5 times the outside diameter of the product pipe in a single pass (ie. concurrent with pipe pull) or in multiple passes (typically when pipe installed diameters are greater than 300mm to 350mm (12 to 14 inches) in diameter).

In addition to transporting the soil cuttings, the drilling fluids aid in maintaining the stability of the drilled borehole preventing the hole from collapsing.

Drilling fluids are pumped through the drill pipe and reamer mixing with and suspending the soil cuttings for transport to the surface, which provides lubrication to reduce pipe friction, and to maintain hole stability. During pullback the swivel prevents rotational forces from the drill pipe being translated to the product pipe.

Steering is accomplished by use of an angled face on the drill head or by a slight bend in the drill pipe just behind the cutting head. To effect changes in direction the drill is rotated to the desired clock angle and the rod pushed forward (ie. if the drill face or bend is orientated to the right the drill path will then proceed to the right.).

Locating and tracking is accomplished by measuring an electromagnetic signal generated by a transmitter located in the drill rod just behind the drill head. The signal strength, and other parameters such as pitch (inclination), roll (clock), and azimuth (direction) which are "attached" to the transmitted signal, and are received above ground by a hand held locator (walkover receiver system). Based on the signal strength, the position (x, y) and depth can be determined for the drill head and compared to a pre-determined borehole alignment.

Where access is not available above the drill head, a wireline system may be utilized where the required drill information is transmitted, via wire, back through the drill string to the drill rig where a computer plots the borehole progress. Where strategic placements are required or magnetic interference may be present, a wire grid is utilized to induce a known magnetic field. Based on the induced signal strength and the known location of the wire grid, the position of the drill head can be determined. Wire line systems utilize nonmagnetic drill collars and drill pipe.

The drilling unit should be equipped with an electrical strike safety package. The package should contain warning sound alarm, grounding mats, and protective safety gear.

PERMIT APPLICATION SUBMITTAL

The permit application package shall contain the following information in support of the permit application.

1. Location of entry and exit point.
2. Equipment and pipe layout areas.
3. Proposed drill path alignment (both plan & profile view).
4. Location, elevations and proposed clearances of all utility crossings and structures.
5. Proposed Depth of cover.
6. **Soil analysis.
7. Product material (HDPE/steel), length, diameter-wall thickness, reamer diameter.
8. Detailed pipe calculations, confirming ability of product pipe to withstand installation loads and long term operational loads including H20.
9. Proposed composition of drilling fluid (based on soil analysis) viscosity and density.
10. Drilling fluid pumping capacity, pressures, and flowrates proposed.
11. State right-of-way lines, property, and other utility right-of-way or easement lines.
12. Elevations.
13. Type of tracking method/system.
14. Survey Grid establishment for monitoring ground surface movement (settlement or heave) due to the drilling operation.

Note: *** May be waived by the District Permit Engineer on HDD jobs of less than 200mm (6") in diameter and on a transverse crossing less than 150' in length.*

ALL ADDITIONAL PERMIT CONDITIONS SHALL BE SET FORTH IN THE SPECIAL PROVISIONS OF THE PERMIT.

The following, outlines recommended depths for various pipe diameters:

RECOMMENDED MINIMUM DEPTH OF COVER	
DIAMETER	**DEPTH OF COVER**
50mm (2 inches) to 150mm (6 inches)	1.2 meters (4 feet)
200mm (8 inches) to 350mm (14 inches)	1.8 meters (6 feet)
375mm (15 inches) to 600mm (24 inches)	3.0 meters (10 feet)
625mm (25 inches) to 1200mm (48 inches)	4.5 meters (15 feet)

The permittee/contractor shall, prior to and upon completion of the directional drill, establish a Survey Grid Line and provide monitoring.

Upon completion of the work, the permittee shall provide an accurate as-built drawing of the installed pipe.

SOIL INVESTIGATIONS

A soil investigation should be undertaken, suitable for the proposed complexity of the installation to confirm ground conditions.

Definition: Soil Analysis

Common sense must be utilized when requiring the extensiveness of the soil analysis. A soil analysis is required in order to obtain information on the ground conditions that the contractor will encounter during the HDD operation.

If, the contractor can go to the project site and do an excavation with a backhoe to one foot below the proposed depth of the bore, that is a soil investigation. In all cases when an excavation is made in creating of an entrance and exit pit for a HDD project, that is an example of a soil investigation. The HDD process is in itself a continual and extensive soil analysis as the pilot bore is made and it encounters the varying soils and formations the drilling slurry will change colors, therefore providing the contractor with continual additional information.

The purpose and intent of the soil analysis is to assist the contractor in developing the proper drilling fluid mixture, and to ensure Caltrans that the contractor is aware of the conditions that do exist in the area of the proposed project. This prepares the contractor in the event they should encounter a zone of pre-tectonics, and that they would need additives or preventive measures in dealing with inadvertent returns (frac-outs).

The discretion on the extensiveness of the soil analysis is left to each individual District Permit Engineer (DPE) respectfully, for their respective areas. The inspectors play a large role in assisting the DPE in making decisions on the extensiveness. Each individual inspector has a general knowledge of the soil conditions in their area of responsibility.

In many circumstances the soil information has already been prepared, either by Caltrans or by City and County Entities. This information if existing should be provided to the requesting permittee, if there is a structure within 1/2 mile of the proposed project, then Caltrans has already done an extensive soil analysis and the information is stored in our Maps & Records Branch. As-Builts, on our freeways and highways provide stationing and detailed information regarding soil information, cut and fill areas.

Determination of Soil Investigations

The District Permit Engineer (DPE) should determine the extensiveness of the Soil Investigation to be performed based on the complexity of the HDD operation, the DPE may recommend according to the guidelines listed below, a combination of, or modify the guideline to fit the respective area:

Projects less than 500' in length, where the product or casing is 8" or less in diameter:

A field soil sampling investigation to a depth of one foot below the proposed drilling.

a) subsurface strata, fill, debris and material

Projects less than 800' in length, where the product or casing is 14" or less in diameter:

A field soil sampling investigation to a depth of one foot below the proposed drilling.
a) subsurface strata, fill, debris and material
b) particle size distribution (particularly percent gravel and cobble)

Projects where the product or casing is 16" or greater in diameter:

A geotechnical evaluation by a qualified soil engineer to determine the following.
a) subsurface strata, fill, debris and material,
b) particle size distribution (particularly percent gravel and cobble),
c) cohesion index, internal angle of friction, and soil classification,
d) plastic and liquid limits (clays), expansion index (clays), soil density
e) water table levels, and soil permeability,

Projects where the product or casing 24" or greater in diameter:

A geotechnical evaluation by a qualified soil engineer to determine the following.
a) subsurface strata, fill, debris and material
b) particle size distribution (particularly percent gravel and cobble)
c) cohesion index, internal angle of friction, and soil classification
d) plastic and liquid limits (clays), expansion index (clays), soil density, and penetration tests,
e) rock strength, rock joint fracture and orientation, water table levels, and soil permeability,
f) areas of suspected and known contamination should also be noted and characterized.

Boreholes or test pits should be undertaken at approximately 75 to 125 meter (250 to 410 feet) intervals where a proposed installations greater than 1000' feet in length and parallel an existing road. For road crossings a borehole or test pit shall be undertaken on either side with one or more additional boreholes or test pits in the median where conditions permit. Additional boreholes or test pits should be considered if substantial variation in soil conditions are encountered.

Should the soil investigation determine the presence of gravel, cobble, and/or boulders, care should be exercised in the selection of drilling equipment and drilling fluids. In such ground conditions the use of casing pipes or washover pipes may be required or specialized drilling fluids utilized. Fluid jetting methods used as a means of cutting **<u>should only be considered</u>** where soils have a high cohesion such as stiff clays.

Directional drilled gravity sewers shall only be considered where suitable soil conditions are present. Suitable soil conditions include homogenous soils consisting of clays, silts, silty sands, and sands that would allow for good control of the drill head during the pilot hole drilling.

PRE-CONSTRUCTION & SITE EVALUATION

The following steps should be undertaken by the permittee/contractor in order to ensure safe and efficient construction with minimum interruption of normal, everyday activities at the site.

1. Notify owners of subsurface utilities along and on either side of the proposed drill path of the impending work through USA alert (the one-call program). All utilities along and

on either side of the proposed drill path are to be located.

2. Obtain all necessary permits or authorizations to carry construction activities near or across all such buried obstructions.
3. All utility crossings should be exposed using a hydro-excavation, hand excavation or other approved method (potholing) to confirm depth.
4. Construction schedule should be arranged so as to minimize disruption (e.g. drilling under railroad beds, major highways, and/or river crossings).
5. The proposed drill path should be determined and documented, including its horizontal and vertical alignments and the location of buried utilities and substructures along the path.

The size of excavations for entrance and exit pits should be of sufficient size to avoid a sudden radius change of the pipe, and consequent excessive deformation at these locations. Sizing the pits is a function of the pipe depth, diameter and material. All pits, over 5' in depth must be shored as required by OSHA regulations.

Walk the area prior to the commencement of the project and visually inspect potential sites. The following should be addressed:

1. When on State R/W establish whether or not there is sufficient room at the site for: entrance and exit pits; HDD equipment and its safe unimpeded operation; support vehicles; fusion machines; stringing out the pipe to be pulled back in a single continuous operation.
2. Establishing suitability of soil conditions for HDD operations (The HDD method is ideally suited for soft sub-soils such as clays and compacted sands. Subgrade soils consisting of large grain materials like gravel, cobble, and boulders make HDD difficult to use and may contribute to pipe damage).
3. Check the site for evidence of substructures such as manhole covers, valve box covers, meter boxes, electrical transformers, conduits or drop lines from utility poles, and pavement patches. HDD may be a suitable method in areas where the substructure density is relatively high.

INSTALLATION REQUIREMENTS

The permittee shall ensure that appropriate equipment is provided to facilitate the installation, in particular the drill rig shall have sufficient pulling capacity to meet the required installation loads determined by the detailed pipe calculations. The drill rig should have the ability to provide pull loads, push loads, torque and the permittee shall ensure that they are monitored during the drilling operation. The permittee shall ensure the drill rod can meet the bend radii required for the proposed installation (a general rule of thumb is 100 times in feet, the diameter of the drill pipes).

During construction continuous monitoring and plotting of pilot drill progress shall be undertaken to ensure compliance with the proposed installation alignment and allow for appropriate course corrections to be undertaken that would minimize “dog legs” should the bore start to deviate from the intended bore path.

Monitoring shall be accomplished by manual plotting based on location and depth readings provided by the locating/tracking system or by computer generated bore logs which map the bore path based on information provided by the locating/tracking system. Readings or plot points shall be undertaken on every drill rod.

For gravity sewer installations or installations where tight control of alignment and grade is required readings shall be undertaken every 1.0 to 1.5 meters (3 to 5 feet). At the completion of the bore an as-built drawing shall be provided. Prior to commencement of a directional drilling operation, proper calibration of the sonde equipment shall be undertaken.

Monitoring of the drilling fluids such as the pumping rate, pressures, viscosity, and density during the pilot bore, back reaming, and/or pipe installation stages, shall be undertaken to ensure adequate removal of soil cuttings and the stability of the borehole is maintained. Excess drilling fluids shall be contained at entry and exit points until recycled or removed from the site. Entry and exit pits should be of sufficient size to contain the expected return of drilling fluids and soil cuttings.

The permittee shall ensure that all drilling fluids are disposed of in a manner acceptable to the appropriate local, state, or federal regulatory agencies. When drilling in contaminated ground the drilling fluid shall be tested for contamination and disposed of appropriately. Restoration of damage to any highway or non-highway facility caused by escaping ("fracout") drilling fluid, or the directional drilling operation, shall be the responsibility of the permittee.

To minimize heaving during pullback, the pull back rate shall be determined which maximizes the removal of soil cuttings and minimizes compaction of the ground surrounding the borehole. The pullback rate shall also minimize overcutting of the borehole during the back reaming operation to ensure excessive voids are not created resulting in post installation settlement.

The permittee shall, prior to and upon completion of the directional drill, establish a Survey Grid Line and provide monitoring as outlined in their submitted detailed monitoring plan. Subsurface monitoring points shall be utilized to provide early indications of settlement as large voids may not materialize during drilling due to pavement bridging.

Should pavement heaving or settlement occur, sawcutting and replacement of the asphalt would be the responsibility of the permittee.

To prevent future settlement should the drilling operation be unsuccessful the permittee shall ensure the backfill of any void(s) with grout or backfilled by other means.

THE ABOVE REQUIREMENTS ARE DESCRIBED FURTHER AS FOLLOWS:

1.0 CONSIDERATIONS

1. ***Different ground conditions:*** The availability of adequate geo-technical information is invaluable in underground construction; it acts to reduce the risk born by the permittee/contractor. However, even in the presence of good geo-technical data, unexpected ground conditions may be encountered.

2. ***Turbidity of Water and Inadvertent Returns:*** Prior to construction beginning, while difficult to predict, events may lead to work stoppage. The permittee/contractor should offer a mechanism to mutually address and mitigate these problems if and when they should arise. For example, contingency plans for containment and disposal of inadvertent returns or frac outs.

2.0 PERMITTEE/CONTRACTOR RESPONSIBILITIES

The permittee/contractor should provide the following items: construction plan; site layout plan; project schedule; communication plan; safety procedures; emergency procedures; company experience record; contingencies plan and drilling fluid management plan.

2.1 CONSTRUCTION PLAN REQUIREMENTS

The permittee shall identify in the construction plan:

1) location of entry and exit pits.
2) working areas and their approximate size.
3) proposed pipe fabrication and layout areas.
4) state right-of-way lines, property lines.
5) other utility right-of way and easement lines.
6) pipe material and wall thickness.
7) location of test pits or boreholes undertaken during the soil investigation.
8) identify the proposed drilling alignment (both plan & profile view) from entry to exit.
9) identify all grades and curvature radii.
10) all utilities (both horizontal and vertical).
11) structures with their clearances from the proposed drill alignment.
12) confirm the minimum clearance requirements of affected utilities and structures.
13) required minimum clearances from existing utilities and structures.
14) diameter of pilot hole, number and size of pre-reams/backreams.
15) Access requirements to site (if required).
16) crew experience.
17) Type of tracking equipment.

2.2 LOCATING AND TRACKING

EFFECTIVE JANUARY 1, 2000, LOCATING AND TRACKING OF THE REAMER DURING THE BACK-REAMING PROCESS IS REQUIRED.

The permittee shall describe the method of locating and tracking the drillhead during the pilot bore. Systems include walkover, wireline, or wireline with wire surface grid. The locating and tracking system shall be capable of ensuring the proposed installation can be installed as intended.

Typical walkover sounds have an effective range of 10 to 15 meters, depending on the Electro-magnetic properties of the soil and the extent of local magnetic interference. Depending on the profile of the borehole, the driller may lose contact with the sound over certain sections of the alignment. If the “blind” section is expected to be too long or in the vicinity of a buried object, the project engineer may specify the use of a wire-line system or a magnetic navigation tool.

The locating and tracking system shall provide the following information:

- Clock and pitch information
- Depth
- Beacon Temperature

- Battery Status
- Position (x,y)
- Azimuth – where direct overhead readings (walkover) are not possible.

Illustration **2.2A** below shows a universal housing that will work with any drill-string on all HDD rigs. The placement of the sonde should be before the backreamer.

This housing can be utilized in the initial pilot bore, after exiting, the cutting head can be removed and the reamer installed.

This housing chamber can utilize any of the sonde batteries manufactured, regardless of manufacturer.

There is also a 2.5" mini-sonde combination available for smaller rigs. This particular model can be seen at the following web site: **www.geologicalboring.com/**

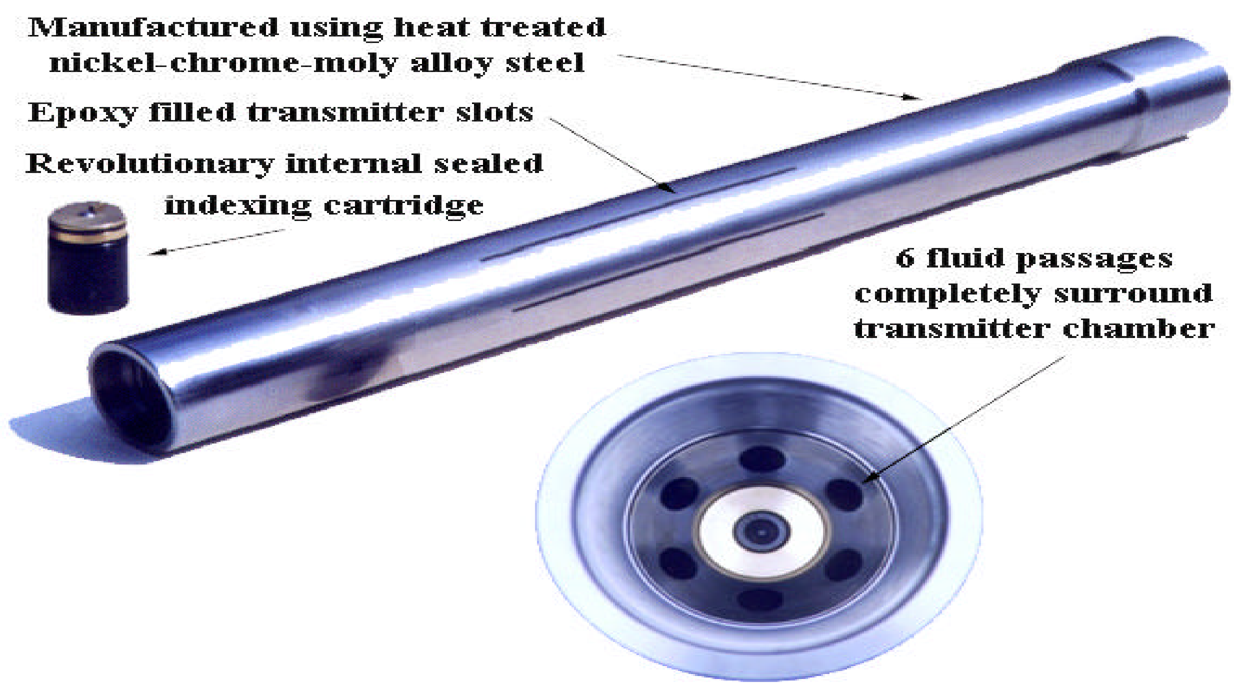

ILLUSTRATION 2.2A

2.3 Drilling Fluids Management Plan

The following information should be provided as part of the drilling fluid management plan:

- Proposed viscosities for soil transportation to the entry and exit pits.
- Estimated pumping capacity and pressures.
- Identify source of fresh water for mixing the drilling mud (Necessary approvals and permits are required for sources such as streams, rivers, ponds, or fire hydrants).
- Method of slurry containment.

- Method of recycling drilling fluid and spoils (if applicable).
- Method of transporting drilling fluids and spoils off site.

Drilling fluid pressures should not exceed that which can be supported by the overburden (soil) pressure.

Drilling fluids serve many functions, as follows:

- Removes cuttings from the bottom of the hole and transports them to the surface.
- Holds cuttings and weight material in suspension when circulation is interrupted.
- Releases sands and cuttings at the surface.
- Stabilizes the hole with an impermeable cake.
- Cools and lubricates the drill bit and drill string
- Controls subsurface pressures.
- Transmits hydraulic horsepower.
- Cools the locating transmitter sonde preventing burnout.

Section 7 provides a more detailed discussion of drilling fluid handling and disposal practices.

2.4 Previous Experience

1. The permittee's contractor should provide a list of projects completed by his company, location, project environment (e.g., urban work, river crossing), product diameter and length of installation.
2. The permittee's contractor should provide a list of key personnel.

2.5 Safety

The drilling unit should be equipped with an electrical strike safety package. The package should include warning sound alarm, grounding mats (if required), and protective gear.

The permittee/contractor should have a copy of the company safety manual including:

2.1 Operating procedures that comply with applicable regulations, including shoring of pits and excavations when required.
2.2 Emergency procedures for inadvertently boring into a natural gas line, live power cable, water main, sewer lines, or a fiber-optic cable, which comply with applicable regulations.
2.3 Emergency evacuation plan in case of an injury.

2.6 Contingency Plans

The Contingency plan should address the following:

a) Inadvertent return, spill (e.g., drilling fluids, and hydraulic fluids), including measures to contain and clean the affected area.
b) clean up of surface seepage of drilling fluids and spoils (i.e., “Frac-out”).

2.7 Communication Plan

The communication plan should address the following:

1. The phone numbers for communication with owner or his representative on the site.
2. Identification of key person(s) which will be responsible for ensuring that the communications plan is followed.
3. Issues to be communicated including safety, progress, and unexpected technical difficulties.

2.8 Traffic Control

1. When required, the permittee/contractor is responsible for supplying and placing warning signs, barricades, safety lights, and flags or flagmen, as required for the protection of pedestrians and vehicle traffic.
2. Obstruction of the roadway, on major road, should be limited to off-peak hours.

3.0 IN ADDITION TO THE PERMIT PACKAGE (IF REQUIRED)

Information that may be required, include other permits, bonding and certification as listed in the following sections.

3.1 Additional Permits that may be required:

1. for obtaining water (ie: hydrants, streams, etc.)
2. for storage, piling and disposal of material.
3. for water/bentonite disposal.
4. Any other permits required carrying out the work.

3.2 Bonding and Certification Requirements

1. Payment bond (if required).
2. Performance bond (if required).
3. Certificate of insurance
4. WCB certificate letter
5. ACSA certificate of recognition

4.0 Drilling Operations

The following paragraphs provide general remarks and rules of thumb related to the directional boring method, as well as specific details regarding various stages of the installation process.

4.1 General

1. Only operators who have State Form TR-0770, "Proof of Training" are permitted to operate the drilling equipment in State R/W.
2. Drilling mud pressure in the borehole should not exceed that which can be supported by the overburden to prevent heaving or a hydraulic fracturing of the soil (i.e. “Frac-out”). Allowing for a sufficient cover depth does this. Typical bore depth of 0.75m to 1.0m

gives pipes with an Outside Diameter (O.D.) of 50-200mm a minimum cover of 0.65m. While circumstances may dictate greater depths, shallower depths are not recommended.

3. The drill path alignment should be as straight as possible to minimize the fractional resistance during pullback and maximize the length of the pipe that can be installed during a single pull.
4. It is preferable that straight tangent sections be drilled before the introduction of a long radius curve. Under all circumstances, a minimum of one complete length of drill rod should be utilized before starting to level out the borehole path.
5. The radius of curvature is determined by the bending characteristics of the product line, and it is increasing with diameter.
6. Entrance angle of the drill string should be between 8 and 20 degrees, with 12 degrees being considered optimal. Shallower angles may reduce the penetrating capabilities of the drilling rig, while steeper angles may result in steering difficulties, particularly in soft soils. A recommended value for the exit angle of the drill string is within the range of 5 to 10 degrees.
7. Whenever possible, HDD installation should be planned so that back reaming and pulling for a leg can be completed on the same day. If necessary, it is permissible to drill the pilot hole and pre-ream one-day, and complete both the final ream and the pull back on the next day.
8. If a drill hole beneath a road must be abandoned, the hole should be backfilled with grout or bentonite to prevent future subsidence.
9. Pipe installation should be performed in a manner that minimizes the over-stressing and straining of the pipe. This is of particular important in the case of a polyethylene pipe.

4.2 Equipment Setup and Site layout

1. Sufficient space is required on the rig side to safely set up and operate the equipment. The workspace required depends on the type of rig used. A small rig may require as little as 3x3m working space, while a large river crossing unit requires a minimum of 30x50m working area. A working space of similar dimensions to that on the rig side should be allocated on the pipe side, in case there is a need to move the rig and attempt drilling from this end of the crossing.
2. If at all possible, the crossing should be planned to ensure that drilling proceed downhill, allowing the drilling mud to remain in the hole, minimizing inadvertent return.
3. Sufficient space should be allocated to fabricate the product pipeline into one string, thus enabling the pull back to be conducted in a single continuous operation. Tie-ins of successive strings during pullback may considerably increase the risk of an unsuccessful installation.

4.3 Drilling and Back-Reaming

1. Drilling mud should be used during drilling and back reaming operations. Using exclusively water may cause collapse of the borehole in unconsolidated soils, while in clays, the use of water may cause swelling and subsequent jamming of the product.
2. Heaving may occur when attempting to back ream too large of a hole. This can be avoided by using several pre-reams to gradually enlarge the hole to the desired diameter.
3. A swivel should be attached to the reamer, or drill rod, to prevent rotational torque being transferred to the pipe during pullback.
4. In order to prevent over stressing of the product during pullback, a weak link, or breakaway-pulling head, may be used between the swirl and the leading end of the pipe.

More details regarding breakaway pulling heads can be found in Section 5.

5. The pilot hole must be back-reamed to accommodate and permit free sliding of the product inside the borehole. A rule of thumb is to have a borehole 1.5 times the product outer diameter. This role of thumb should be observed particularly the larger diameter installations (≥ 250mm O.D.). Some recommended values for final pre-ream diameter as a function of the product O.D. are given in Table II. These values should be increased by 25% if excessive swelling of the soil is expected to occur or the presence of boulders/cobbles is suspected.

Table II: Recommended Back-Ream Hole Diameter (Popelar et al., 1997)

Nominal Pipe Diameter (millimeters)	Back-Ream Hole Diameter (millimeters)
50	75 to 100
75	100 to 150
100	150 to 200
150	250 to 300
200	300 to 350
250	350 to 400
≥300	At least 1.5 times product OD

6. The conduit must be sealed at either end with a cap or a plug to prevent water, drilling fluids and other foreign materials from entering the pipe as it is being pulled back.
7. Pipe rollers, skates or other protective devices should be used to prevent damage to the pipe from the edges of the pit during pullback, eliminate ground drag or reduce pulling force and subsequently reduce the stress on the product.
8. The drilling mud in the annular region should not be removed after installation, but permitted to solidify and provide support for the pipe and neighboring soil.

4.4 Tie-Ins and Connections

1. Trenching may be used to join sections of conduits installed by the directional boring method.
2. An additional pipe length, sufficient for joining to the next segment, should be pulled into the entrance pit. This length of the pipe should not be damaged or interfere with the subsequent drilling of the next leg. The contractor should leave a minimum of 1m of conduit above the ground on both sides of the borehole.

4.5 Alignment & Minimum Separation

The product should be installed to the alignment and elevations shown on the drawings within the pre-specified tolerances (tolerance values are application dependent, for example, in a major river crossing, a tolerance of ±4 m from the exit location along the drill path centerline may be an acceptable value). This tolerance is not acceptable when installing a product line between manholes. Similarly, grade requirements for a water forcemain are significantly different from those on a gravity sewer project.

When a product line is installed in a crowded right-of-way, the issue of safe minimum separation distance arises. Many utility companies have established regulations for minimum separation distances between various utilities. These distances needed to be adjusted to account for possible minor deviation when a line product is installed using HDD technology. As a rule of thumb, if the separation distance between the proposed alignment and the existing line is 5 meters or more, normal installation procedures can be followed. If the separation is 1.5 meters or less, special measures, such as observation boreholes are required. The range between 1.5 and 5 meters is a “gray” area, typically subject to engineering judgement (a natural gas transmission line is likely to be treated more cautiously than a storm water drainage line).

5.0 BREAK-AWAY PULLING HEAD

Recent reports from several natural gas utility companies reveal concerns regarding failure experienced on HDPE pipes installed by horizontal directional drilling (Troch and Doyle, 1998). These failures were attributed to deformation of the pipe due to the use of excessive pulling force during installation. A mitigation measure adopted by some gas companies involves the use of breakaway swivels to limit the amount of force used when pulling HDPE products. Some details regarding these devices and their applications are given below.

1. The weak link used can be either a small diameter pipe (but same SDR) or specially manufactured breakaway link. The latter consists of a breaking pin with a defined tensile strength incorporated in a swivel. When the strength of the pin is exceeded it will break, causing the swivel to separate. A summary of pulling head specifications is given in Table III (all products are SDR 11). "Note that the values provided in Table III could be considered conservative."

Table III: Pulling Head Specifications (Troch and Doyle, 1998)

Pipe Diameter (in.)	Diameter of Break-Away Swivel (in.)	Maximum Allowable Pulling Force (lb.)
1 ¼	7/8	850
2	1 ¼	1,500
4	1 3/8	5,500
6	2 ½	12,000
8	3	18,500

2. The use of breakaway swivels is particularly warranted when installing small diameter HDPE pipes (up to 4” O.D.). Application of such devices in the installation of larger diameter products is not currently a common practice.
3. If the drilling equipment rated pulling capacity is less than the safe load the use of a weak link may not be required.
4. Exceeding the product elastic limit can be avoided simply by following good drilling practices, namely: regulating pulling force; regulating pulling speed; proper ream sizing; and using appropriate amounts of drilling slurry fluid.

6.0 PROTECTIVE COATINGS

In an HDD installation, the product may be exposed to extra abrasion during pullback. When installing a steel pipe, a form of coating which provides a corrosion barrier as well as an abrasion barrier is recommended during the operation, the coating should be well bonded and have a hard smooth surface to resist soil stresses and reduce friction, respectively. A recommended type of coating for steel pipes is mill applied Fusion Bonded Epoxy.

7.0 DRILLING FLUID - COLLECTION AND DISPOSAL PRACTICES

The collection and handling of drilling fluids and inadvertent returns has been one of the most debated topics, the need to keep drilling fluids out of streams, streets and municipal sewer lines.

1. Drilling mud and additives to be used on a particular job should be identified in the permit package, and their Material Safety Data Sheets (MSDS) should be provided to the Permit Office.
2. Excess drilling mud slurry shall be contained in a lined pit or containment pound at exit and entry points, until recycled or removed from the site. Entrance and exit pits should be of sufficient size to contain the expected return of drilling mud and spoils.
3. Methods to be used in the collections, transportation and disposal of drilling fluids, spoils, and excess drilling fluids should be in compliance with local ordinances, regulations and environmentally sound practices in an approved disposal site.
4. When working in an area of contaminated ground, the slurry should be tested for contamination and disposed of in a manner, which meets government requirements.
5. Precautions should be taken to keep drilling fluids out of the streets, manholes, sanitary and storm sewers, and other drainage systems, including streams and rivers.
6. Recycling drilling fluids is an acceptable alternative to disposal.
7. The contractor shall make all diligent efforts to minimize the amount of drilling fluids and cuttings spilled during the drilling operation, and shall provide complete clean-up of all drilling mud overflows or spills.

8.0 SITE RESTORATION AND POST CONSTRUCTION EVALUATION

1. All surfaces affected by the work shall be restored to their pre-construction conditions. Performance criteria for restoration work will be similar to those employed in traditional open excavation work.
2. If required, the permittee/contractor shall provide a set of as-built drawings including both alignment and profile. Drawings should be constructed from actual field readings. Raw data should be available for submission at any time upon request. As part of the "As-Built" document the contractor shall specify the tracking equipment used, including method or confirmatory procedure used to ensure the data was captured.

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APPENDIX A - BASIC TERMINOLOGY

Approach Angle: The angle between the drill stem and the ground surface at the surface entry point. Depending on the type of rig being used, this angle may vary from 7° to 90° to the horizontal. An angle of less than 30° is most common.

Back-Reamer: A tool attached to end of the drill string and pulled through the bore to enlarge the hole and mix the cuttings with the drilling fluid.

Bentonite: Absorbent aluminum silicate clay formed from volcanic ash. When thoroughly mixed with water, bentonite breaks down into small particles called platelets. The platelets plaster or shingle off the wall of the bore and form a filter cake that cuts off the flow of the water into the surrounding formation.

Compaction Head: A drilling head that is used in soft soils and compacts the pilot bore hole.

Combination Head: A drilling head that has both the action of compaction and cutting into one.

Cutting Head: A drilling head that is used for tougher soils and roots.

Cuttings: Spoils particles, also known as drilling spoils, created during the boring process. Use of proper drilling fluid will help to suspend the cuttings that reduce the risk of getting stuck during drilling or back reaming.

Duckbill: The drilling bit that is attached to the front of the boring head. It mounts on the head at an angle and is also bent. This angle is what provides the steering capability while pushing the drilling string.

Exit pit: The area where the drill pipe exits the ground and the service lines are pulled back.

Frac-out: Under certain conditions, the drilling fluid can build a large pressure in the borehole. If the pressure become great enough, the ground will fracture, allowing the drilling fluids to escape the bore.

Mud: Drilling fluids.

Polymer: Natural synthetic compounds of high molecular weight. Polymers, when used in conjunction with bentonite in the drilling fluid, enhance viscosity and gel strength, lowers filtration rate, and increases lubricity. The use of polymer is recommended when boring in clay or shale.

Rack: The actual boring machine that includes the drive head, controls, vise, etc.

Radius of Curvature: The radius of curvature, which typically ranges between 150 and 800 feet, defines the curved portion of the borehole. The greater the borehole radius of curvature, the greater the total borehole length. The benefit of a higher radius of curvature (reduced stress on drilling equipment and pipeline product) must be balanced against the additional cost of drilling a longer borehole.

Roll: The rotational position of the drill head as it relates to a clock face.

Sonde: An electronic device that fits inside the drill head and transmits a signal used for locating purposes. Also referred to as a transmitter or probe.

Step-off Distance: The horizontal distance between the entry hole and the beginning of the horizontal section of the borehole. This is usually determined by the open area available for setting up the drilling equipment and the type of product to be installed.

Strike alert: A warning system that is set off by contact with electrical power source.

Swivel: Attaches between the back reamer and the product being pulled back to keep the product from twisting.

Thrust: The rig capacity to push the drill stem into the ground without rotating.

Torque: The rotational force applied to the drill stem joints.

Wetting agent: A substance that reduces the surface tension of a liquid, causing the liquid to spread across or penetrate more easily the surface of a solid. A soap-based wetting agent reduces the tendency of clay cuttings to stick together. It also reduces the tendency of the boring tools becoming stuck due to adhesion.